

Real-Time and Accelerated Solar Weathering of Commercial PV Modules

Preprint

C.R. Osterwald, J. Pruetz, D.R. Myers,
S. Rummel, A. Anderberg, L. Ottoson, and
T. Basso

*To be presented at the NCPV Program Review Meeting
Lakewood, Colorado
14-17 October 2001*



NREL

National Renewable Energy Laboratory

1617 Cole Boulevard
Golden, Colorado 80401-3393

NREL is a U.S. Department of Energy Laboratory
Operated by Midwest Research Institute • Battelle • Bechtel

Contract No. DE-AC36-99-GO10337

NOTICE

The submitted manuscript has been offered by an employee of the Midwest Research Institute (MRI), a contractor of the US Government under Contract No. DE-AC36-99GO10337. Accordingly, the US Government and MRI retain a nonexclusive royalty-free license to publish or reproduce the published form of this contribution, or allow others to do so, for US Government purposes.

This report was prepared as an account of work sponsored by an agency of the United States government. Neither the United States government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States government or any agency thereof.

Available electronically at <http://www.osti.gov/bridge>

Available for a processing fee to U.S. Department of Energy
and its contractors, in paper, from:

U.S. Department of Energy
Office of Scientific and Technical Information
P.O. Box 62
Oak Ridge, TN 37831-0062
phone: 865.576.8401
fax: 865.576.5728
email: reports@adonis.osti.gov

Available for sale to the public, in paper, from:

U.S. Department of Commerce
National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
phone: 800.553.6847
fax: 703.605.6900
email: orders@ntis.fedworld.gov
online ordering: <http://www.ntis.gov/ordering.htm>



Printed on paper containing at least 50% wastepaper, including 20% postconsumer waste

Real-Time and Accelerated Solar Weathering of Commercial PV Modules

C.R. Osterwald, J. Pruett, D.R. Myers, S. Rummel, A. Anderberg, L. Ottoson, and T. Basso
National Renewable Energy Laboratory
1617 Cole Blvd.
Golden CO 80401-3393

ABSTRACT

Since 1997, using existing ASTM standards for weathering of materials, we have been conducting a solar weathering program on a group of six different types of photovoltaic (PV) modules. The methods used include real-time outdoor, accelerated outdoor, and accelerated indoor weathering. We have employed the technique specified in these standards that quantifies exposure totals by the time integral of the ultraviolet (UV) irradiance. In this paper, we report the observed degradation in the test modules as a function of total UV exposure, and give a number of recommendations for future weathering tests that resulted from our first attempt at a formal test program.

1. Introduction

Real-time and accelerated weathering of materials, particularly paints and plastics, are well-established practices that have been codified as ASTM standards [1-4]. Later, another ASTM standard [5] was developed specifically for PV modules. All of these standards quantify the total exposure by the UV irradiance, integrated over time. The purpose of this work was to perform controlled weathering of PV modules using these standard practices. Results of this weathering program were to include not only any degradation of the test modules, but also general recommendations and pitfalls to avoid in the future.

2. Test Program Design

A number of test systems are available at the NREL Outdoor Test Facility for light exposure of PV modules. Latitude-tilt (40°) equator-facing racks are used for real-time outdoor exposure, and a two-axis solar tracker called the Outdoor Accelerated-weathering Tracking System (OATS) can expose modules both with and without mirror concentration. The OATS mirrors provide a maximum of approximately 3× concentration. Indoors, an Atlas XR-260 Weatherometer has four 4-kW Xe arc lamps inside a large environmental chamber, and another chamber has a row of 48 fluorescent UV lamps of the “A” range (UVA-340). Although E 1596 [5] does not allow fluorescent UV exposure, these lamps are widely used in the PV industry and are also allowed for the short-duration UV conditioning test specified in the IEEE module qualification sequence [6]. It was therefore decided to include UVA exposure in this weathering experiment. Both of the indoor exposure systems provide temperature control. Cooling fans on the OATS 3× are used to prevent very high (>75°C) module temperatures under concentration.

Because the test planes in the accelerated exposure systems are only about 1.5 m by 2 m in area, full-size modules could not be exposed without limiting the total number of test modules. We therefore decided to test smaller, commercially avail-

able modules in the 5-20 W output power range. Six different models from three manufacturers were purchased in 1995, with two types of single-crystal Si, two types of polycrystalline Si, and two types of a-Si modules. One set of six modules was retained as a control, for a total of 36 modules. The PV weathering standard does not specify a loading condition, so we arbitrarily decided to operate all the test modules with resistive loads equivalent to their maximum power points under standard test conditions.

For the weathering exposure limit, reference [4] specifies 2000 MJ/m² of wavelengths shorter than 385 nm, and we decided to use this value as the limit for our tests. Real-time exposure in Golden, CO, results in an average of about 270 MJ/m² per year, so this limit represents about 7.5 years outdoors at our location.

3. Irradiance and Temperature Limits

UV irradiances were measured with Eppley TUVR radiometers, which have nearly zero responsivity to wavelengths greater than 385 nm. This wavelength cutoff is also how E 1596 [5] defines UV for the purposes of total exposure measurements. However, the UV conditioning test in IEEE 1262 [6] specifies 400 nm, so we decided to use this definition instead (although the total exposure limit was not adjusted accordingly). The exposure methods we used have different spectral irradiance distributions, which must be accounted for in total exposure measurements. The ratios of integrated UV irradiance up to 400 nm to integrated UV below 385 nm are 1.37, 1.04, and 1.26 for the XR-260, UVA-340, and outdoors, respectively. For outdoor measurements, the 1.26 ratio is an approximation for our location and is based on a number of spectral measurements made at various times throughout the year. Because of this factor, 2000 MJ/m² of UV less than 400 nm requires about 5.9 years outdoors. All radiometers were calibrated according to ASTM G 130 [7].

Table 1 lists maximum total and UV irradiances, and module temperatures encountered during exposure testing.

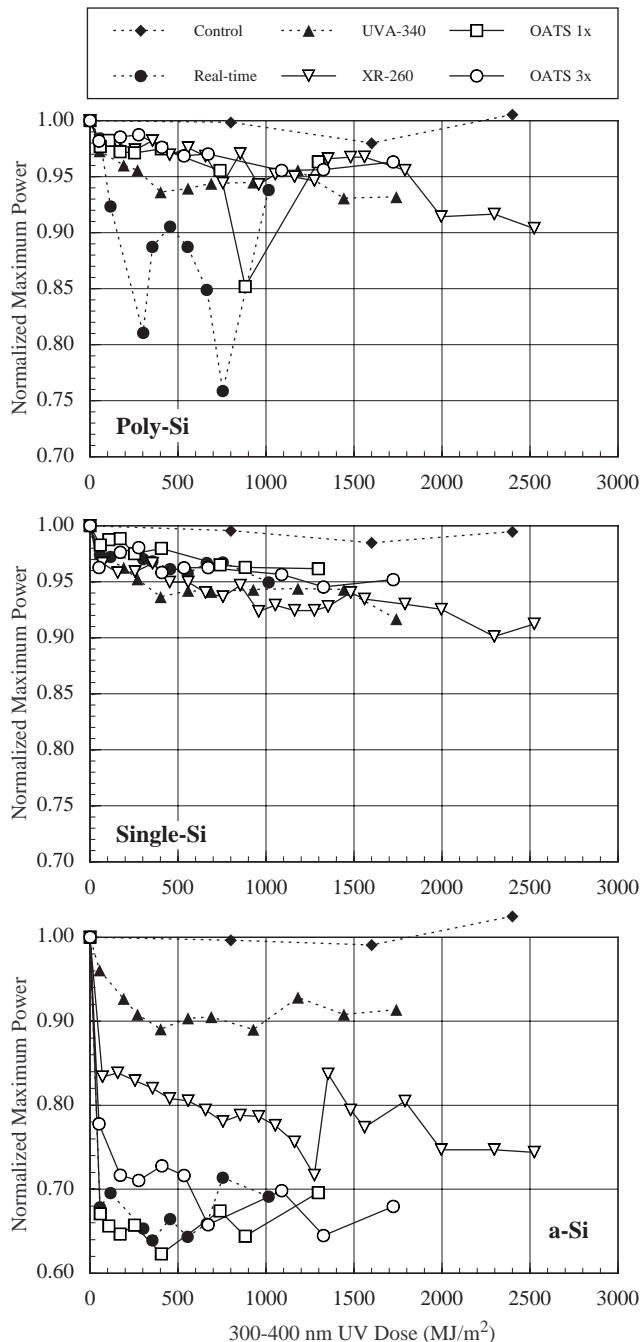
Exposure	Total Irrad. (W/m ²)	UV Irrad. (W/m ²)	Module Temp. (°C)
Real-time	1100	70	(not measured)
OATS 1×	1200	75	45-55
OATS 3×	3500	110	45-75
XR-260	2000	50	45-60
UVA-340	40	40	50-65

Table 1. Maximum total irradiances, UV (less than 400 nm) irradiances, and back-of-module temperatures for each of the five weathering methods used for this study.

4. Results

The solar weathering program began in Sept. 1997, and Figs. 1–3 show changes in module maximum power as a function of total exposure for three of the six module types. All the crystalline Si types showed an initial degradation of 2%–3%.

For the polycrystalline Si module type in Fig. 1, the real-time data show large swings in performance. We determined these were caused by corrosion of contacts external to the modules that were used for both the resistive loading and for current-voltage curves. Replacement of these contacts restored the output, as seen by the 1000 MJ/m² data point.



Figs. 1–3. Normalized module maximum power, measured with a Spire 240A solar simulator, versus total UV exposure dose (MJ/m²), for three of the six module types in this study. Note that the control modules were not exposed.

The average degradation observed for single-crystal Si in Fig. 2 is 3.03% per 1000 MJ/m², which translates to 1.03% per year for our location ($0.00303 \times 270 \times 1.26$). In the XR-260 and UVA-340 cases, this module type developed visible browning at the four corners and along the edges.

In Fig. 3, the well-known initial Staebler-Wronski a-Si degradation can be seen. Aside from this, the only degradation observable is perhaps the XR-260 data. The levels in Fig. 3 can be explained in terms of the total (not the UV) irradiance and temperature. Because the indoor accelerated methods keep the module temperatures nearly constant, a-Si photon degradation is partly annealed and these modules show smaller losses compared with the outdoor methods, in which modules periodically operate in cold temperatures during winter.

5. Conclusions and Recommendations

Using well-established solar weathering methods with UV radiometry appears to be a good choice for quantifying accelerated and real-time exposure of PV modules. We have obtained a degradation rate that is identical to the commonly reported rule of thumb for crystalline Si modules, 1% per year. Because the UV irradiance for two-axis tracking without mirrors is only slightly higher than the fixed exposure racks, it is not a useful method of accelerated weathering. UV exposures should be quantified for wavelengths less than 385 nm, rather than 400 nm as used by IEEE 1262 [6].

6. Acknowledgement

This work was supported by the U.S. Department of Energy under contract No. DE-AC36-99-G010337.

REFERENCES

- [1] ASTM Standard G 7, "Practice for Atmospheric Environmental Exposure Testing of Nonmetallic Materials," ASTM Annual Book of Standards, Vol. 14.04, West Conshohocken, PA, 2001.
- [2] ASTM Standard G 26, "Practice for Operating Light-Exposure Apparatus (Xenon-Arc Type) With and Without Water for Exposure of Nonmetallic Materials," ASTM Annual Book of Standards, Vol. 14.04, West Conshohocken, PA, 2001.
- [3] ASTM Standard G 90, "Practice for Performing Accelerated Outdoor Weathering of Nonmetallic Materials Using Concentrated Natural Sunlight," ASTM Annual Book of Standards, Vol. 14.04, West Conshohocken, PA, 2001.
- [4] ASTM Standard G 154, "Practice for Operating Fluorescent Light Apparatus for UV Exposure of Nonmetallic Materials," ASTM Annual Book of Standards, Vol. 14.04, West Conshohocken, PA, 2001.
- [5] ASTM Standard E 1596, "Test Methods for Solar Radiation Weathering of Photovoltaic Modules," ASTM Annual Book of Standards, Vol. 12.02, West Conshohocken, PA, 2001.
- [6] IEEE Standard 1262, "IEEE Recommended Practice for Qualification of Photovoltaic (PV) Modules," IEEE, New York, NY, ISBN 1-55937-586-8, 1995.
- [7] ASTM Standard G 130, "Test Method for Calibration of Narrow- and Broad-Band Ultraviolet Radiometers Using a Spectroradiometer," ASTM Annual Book of Standards, Vol. 14.04, West Conshohocken, PA, 2001.